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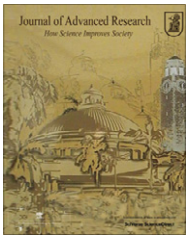

ORIGINAL ARTICLE

Design of aerospace control systems using fractional PID controller

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Abstract The goal is to control the trajectory of the flight path of six degree of freedom flying body model using fractional PID. The design of fractional PID controller for the six degree of freedom flying body is described. The parameters of fractional PID controller are optimized by particle swarm optimization (PSO) method. In the optimization process, various objective functions were considered and investigated to reflect both improved dynamics of the missile system and reduced chattering in the control signal of the controller.

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Introduction and literature review

In recent years, the requirements for the quality of automatic control increased significantly due to increased complexity of plants and sharper specifications of product. This paper will address the design of optimal variable structure controllers applied to a six degree of freedom missile model which is the solution to obtain a detailed accurate data about the missile trajectory. The paper objectives are: (a) to develop a general flexible sophisticated mathematical model of flight trajectory simulation for a hypothetical anti-tank missile, which can be used as a base line algorithm contributing for design, analysis, and development of such a system and implement this model using Simulink to facilitate the design of its control system, and (b) developing control system, by using fractional PID control techniques.

According to MacKenzie, guidance is defined as the process for guiding the path of an object toward a given point, which in general is moving [1]. Furthermore, the father of inertial navigation, Charles Stark Draper, states that "Guidance depends upon fundamental principles and involves devices that are similar for vehicles moving on land, on water, under water, in air, beyond the atmosphere within the gravitational field of earth and in space outside this field" [2]. The most rich and mature literature on guidance is probably found within the guided missile community. A guided missile is defined as a space-traversing unmanned vehicle that carries within itself the means for controlling its flight path [3]. Guided missiles have been operational since World War II [1]. Today, missile guidance theory encompasses a broad spectrum of guidance

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Nomenclature

C_x	drag coefficient
C_y	lift coefficient
C_z	lateral coefficient
D	diameter of maximum cross-section area (m)
F_x, F_y, F_z	components of total forces acting on missile (N)
F	fitness function
G	gravity force (N)
G_x, G_y, G_z	gravity force components (N)
I	moment of inertia (kg m^2/s)
I_x, I_y, I_z	moment of inertia components (kg m^2/s)
J	cost function (objective function)
k_p	proportional gain
k_i	integral gain
k_d	derivative gain
M_{THx}, M_{THy}, M_{THz}	thrust moment components (N m)
M_{Ax}, M_{Ay}, M_{Az}	aerodynamic moment components (N m)
M_x, M_y, M_z	components of total moments acting on missile (N m)
m	the mass of missile (kg)
m_{x0}, $m_{y\beta}$, m_{y0}, $m_{z\alpha}$, m_{z0}	aerodynamic moment coefficients
R_x, R_y, R_z	aerodynamic force components (N)
r	reference signal
S	reference area (m^2)
T	thrust force (N)
T_x, T_y, T_z	thrust force components (N)
V_m	missile velocity (m/s)
w	weight factor
X	range of missile (m)
X_g, Y_g, Z_g	ground coordinate
X_b, Y_b, Z_b	body coordinate
X_V, Y_V, Z_V	velocity coordinate
X_{cg}	distance between cg and the nozzle (m)
Φ, Ψ, γ	Euler's angles (°)
Φ_p	pitch demand programmer (°)
Ψ_p	yaw demand programmer (°)
α, β	angles of attack (°)
δ	fractional derivative
δ_α	jet deflection angle in the pitch plane (°)
δ_β	jet deflection angle in the yaw plane (°)
λ	fractional integration
$\omega_x, \omega_y, \omega_z$	angular velocity components (rad/s)

laws as classical guidance laws, optimal guidance laws, guidance laws based on fuzzy logic and neural network theory, differential geometric guidance laws and guidance laws based on differential game theory. Very interesting personal accounts of the guided missile development during and after World War II can be found in the literature [5,7,9]. Moreover, Locke and Westrum put the development of guided missile technology into a larger perspective [10,15].

Methodology

Mathematical model of the missile

The model constitutes the six degree of freedom (6-DOF) equations that break down into those describing kinematics, dynamics (aerodynamics, thrust, and gravity), command guidance generation systems, and autopilot (electronics, instruments, and actuators). The input to this model is launch conditions, target motion, and target trajectory characterization, while the outputs are the missile flight data (speed, acceleration, range, etc.) during engagement.

The basic frames needed for subsequent analytical developments are the ground, body and velocity coordinate systems. The origins of these coordinate systems are the missile center of gravity (cg). In the ground coordinate system, the X_g–Z_g lie in the horizontal plane and the Y_g axis completes a standard right-handed system and points up vertically. In the body coordinate system, the positive X_b axis coincides with the missile's center line and it is designated as roll-axis. The positive Z_b axis is to the right of the X_b axis in the horizontal plane and it is designated as the pitch axis. The positive Y_b axis points upward and it is designed as the yaw axis. The body axis system is fixed with respect to the missile and moves with the missile. In the velocity coordinate system, X_V coincides with the direction of missile velocity (V_m), which related to the directions of missile flight. The axis Z_V completes a standard right-handed system [4,6].

The pitch plane is X–Y plane, the yaw plane is X–Z plane, and the roll plane is Y–Z plane. The ground coordinate system and body coordinate system are related to each other through Euler's angles (Φ, Ψ, γ). The ground coordinate system and velocity coordinate system are related to each other through the angles (θ, σ). In addition, the velocity coordinate system is related to the body frame through the angle of attack (α) in the pitch plane and sideslip angle (β) in the yaw plane. The angles between different coordinate systems are shown in Fig. 1a [4,6].

The relation between the body and the velocity coordinate systems can be given as follows:

$$\begin{bmatrix} X_b \\ Y_b \\ Z_b \end{bmatrix} = \begin{bmatrix} \cos(\alpha)\cos(\beta) & \sin(\alpha) & -\cos(\alpha)\sin(\beta) \\ -\sin(\alpha)\cos(\beta) & \cos(\alpha) & \sin(\alpha)\sin(\beta)sin(\beta)0\cos(\beta) \end{bmatrix} \begin{bmatrix} X_V \\ Y_V \\ Z_V \end{bmatrix} \tag{1}$$

The body and velocity axes system as well as forces, moments and other quantities are shown in Fig. 1b.

There are 6 dynamic equations (3 for translational motion and 3 for rotational motion) and 6 kinematic equations (3 for translational motion and 3 for rotational motion) for a missile with six degrees of freedom. The equations are somewhat simpler, if the mass is constant. The missile 6-DOF equations in velocity coordinate system are given as following [4]:

$$F_x = m\dot{V}_m \tag{2}$$

$$F_y = mV_m\dot{\theta} \tag{3}$$

$$F_z = -mV_m\cos(\theta)\dot{\sigma} \tag{4}$$

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